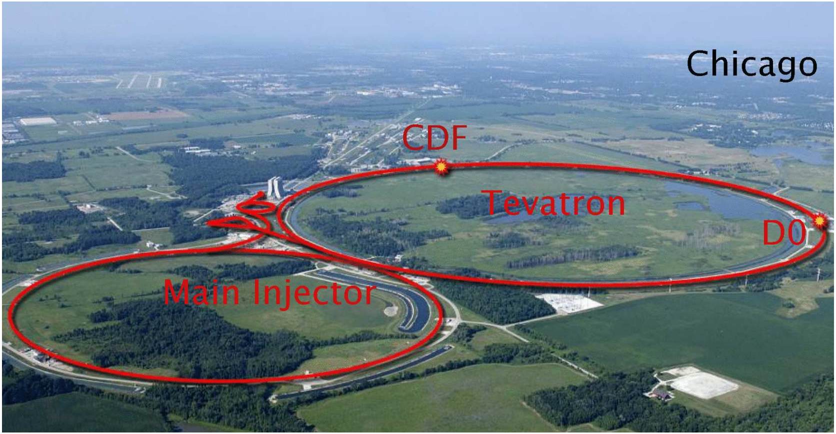
Higgs Boson Searches at CDF

Craig Group
for the CDF Collaboration

Fermilab

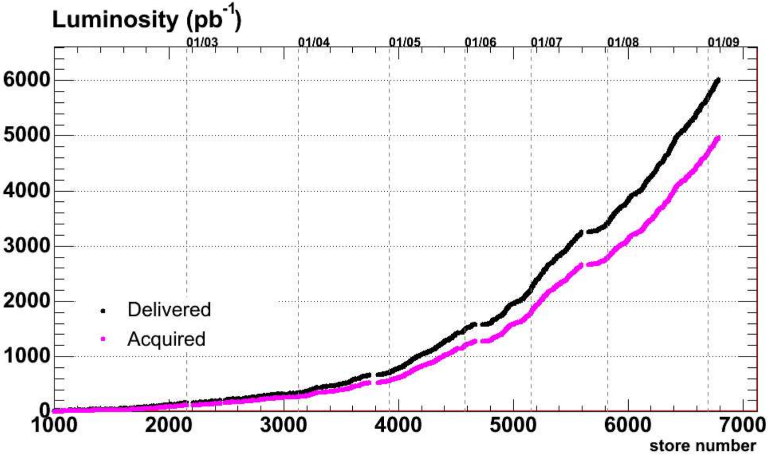
Lake Louise Winter Institute 2009

FNAL: Fermi National Accelerator Lab



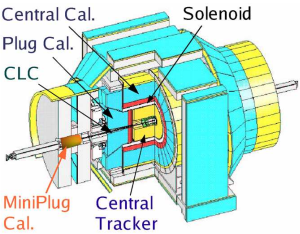
The Tevatron currently provides the highest energy proton-antiproton collisions in the world: $\sqrt{s} = 1.96$ TeV

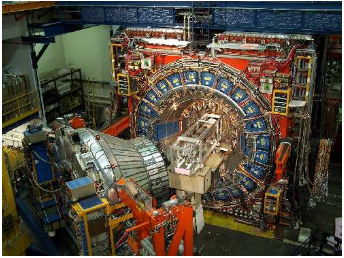
Tevatron Performance



About 5 fb^{-1} of integrated luminosity recorded by CDF
(Today's results use up to 3 fb^{-1})

The CDF Experiment



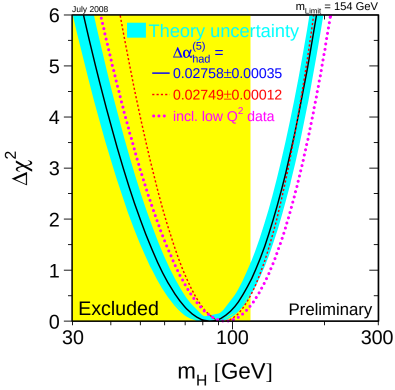


General-purpose detector:

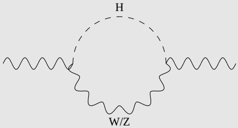
- Luminosity measurement
- Silicon vertex detector
- Central tracking chamber
- Electromagnetic Calorimeters: Jets, e, and γ
- Hadronic Calorimeters: Jets
- Muon chambers

Standard Model Higgs

- EW symmetry breaking introduced into the SM via the Higgs mechanism
  - Allows for fermion and boson mass terms in SM
  - Predicts a massive particle : The **Higgs** boson
  - Not yet observed: opportunity for the Tevatron!



Example: W/Z mass



- Indirect EW constraints:

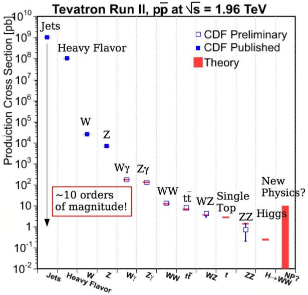
$$m_H < 154 \text{ GeV}$$

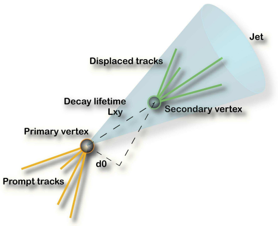
- LEP direct searches:

$$m_H > 114 \text{ GeV}$$

Higgs Searches at CDF in a Nutshell

- The Challenge: extract Higgs signal from a background 10 orders of magnitudes larger
- Triggers
  - High p_T leptons (e, μ), MET+Jets, ...
- Lepton ID: optimized on large W/Z samples
- *b*-jet tagging
  - Multiple “b-tagging” categories
  - NN flavor separator
- Background estimation
  - MC predictions: W/Z+jets, diboson, top,...
  - Data driven: mistags, QCD
- Advance analysis techniques
  - To separate signal from background
  - Neural Network (NN), Matrix Elements (ME), Boosted Decision Trees (BDT),...
  - Exhaustive checks in control regions





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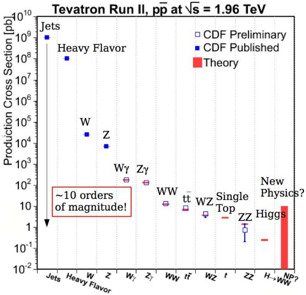
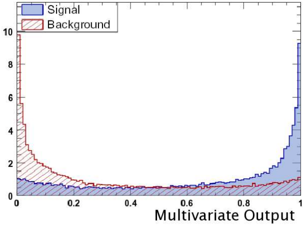
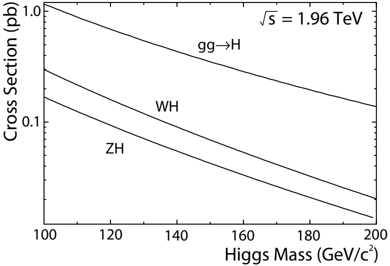


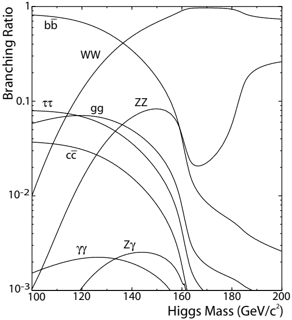


SM Higgs: Tevatron Production and Decay

- Low mass ($m_H <\sim 135$GeV):
  - $H \to b\bar{b}$ dominant decay
  - $gg \to H \to b\bar{b}$ overwhelmed by background
  - Search for associated W/Z production

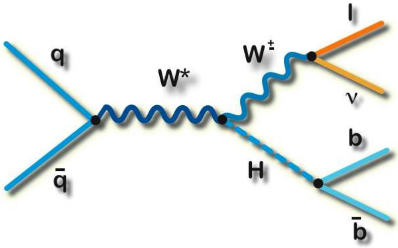


- High mass ($m_H >\sim 135$GeV):
  - $H \to WW$ dominant decay
  - Background low enough to use $gg \to H$



Ultimately, multiple channels are combined within CDF and with DØ.

Low Mass: $WH \to \ell\nu b\bar{b}$



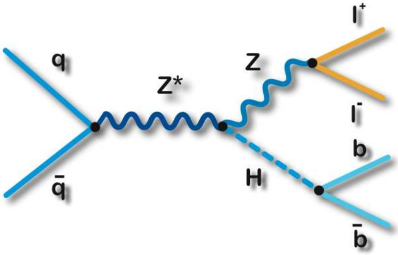
- Most sensitive channel at low mass
- Extended lepton coverage
- Two analyses:
  - NN: exploits kinematic variables
  - BDT+ME: exploits kinematic variables + ME info + NN flavor separator
- Combination of above using evolved NN ($\sim$ 10% improvement)

Results

Analysis	Lumi. (fb^{-1})	Exp. Limit	Obs. Limit
CDF NN	2.7	5.8	5.2
CDF ME+BDT	2.7	5.2	6.2
CDF combo	2.7	4.8	5.6

$m_H = 115$ GeV: 95%CL Limit in $\sigma/$SM

Low Mass: $ZH \rightarrow \ell^+\ell^- b\bar{b}$



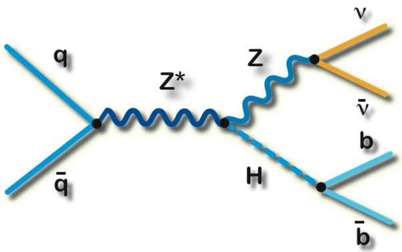
- Cleanest signature but low signal rate
- Main background: Z+jets
- 2D NN: improved dijet mass resolution with MET projection technique
- New ME analysis

Results

Analysis	Lumi. (fb^{-1})	Exp. Limit	Obs. Limit
CDF NN	2.7	9.9	7.1
CDF ME (120 GeV)	2.0	15.0	14.2

$m_H = 115$ GeV: 95%CL Limit in $\sigma/$SM

Low Mass: $VH \rightarrow$MET $b\bar{b}$



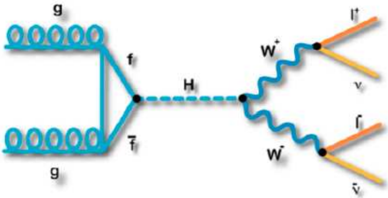
- Also sensitive to WH where ℓ is undetected
- Challenge: building a model (data driven) for QCD background
- NN analysis
  - QCD-NN with missing-pT to reject background
  - Uses of H1 Jet Algorithm combining tracking and calorimeter information
  - Add 3rd jet to include $W \rightarrow \tau\nu$ acceptance

Results

Analysis	Lumi. (fb^{-1})	Exp. Limit	Obs. Limit
CDF NN	2.1	5.6	6.9

m_H = 115 GeV: 95%CL Limit in σ/SM

High Mass: $H \to W^+W^-$



- Most sensitive Higgs search at the Tevatron
- Leptons in same directions due to spin correlation
- ME+NN analysis, analyze separately final states with 0, 1 and $\geq$2 jets
- Also contributes at lower mass
- **Approaching SM sensitivity at 160-170 GeV !**

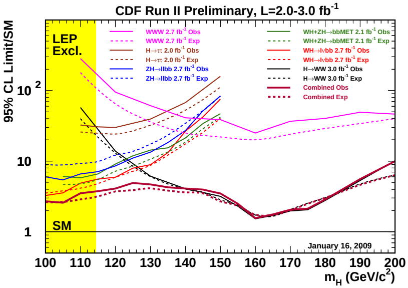
Results

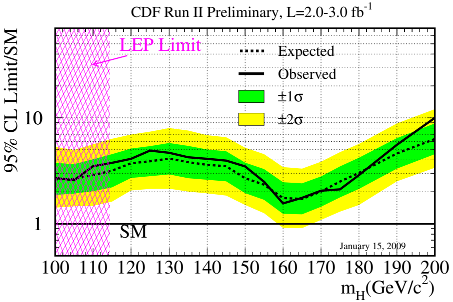
Analysis	Lumi. (fb^{-1})	Exp. Limit	Obs. Limit
CDF ME+NN	3.0	1.6	1.7

$m_H = 165$ GeV: 95%CL Limit in $\sigma/$SM

SM Higgs Combined Limits

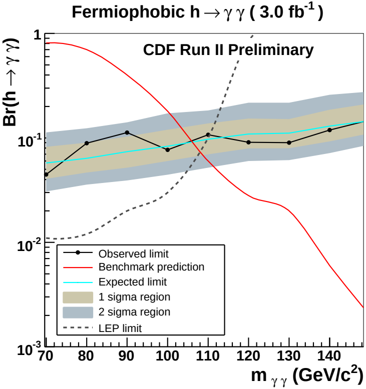
- Systematics and their correlation between channels and experiments taken into account
- Difficult combination with over 70 nuisance parameters
- CDF combined expected (observed) limits:
  - 115 GeV: 3.2 (3.8) $\times$ SM
  - 165 GeV: 1.6 (1.6) $\times$ SM





Combination with DØ provides about $\sqrt{2}$ in improved sensitivity

BSM Example : Fermiophobic Higgs



$H \rightarrow \gamma\gamma$ enhanced in fermiophobic model

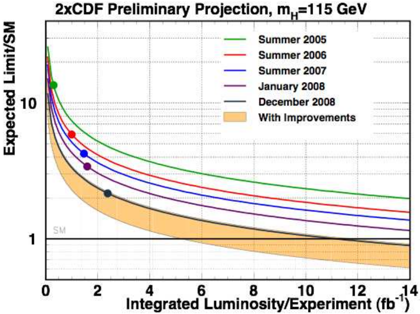
- Photon energy resolution much better than jets
- Look for peak in di-photon mass
- Limit mass of Fermiophobic Higgs above 106 GeV.

Potential to add sensitivity for low mass SM combination...

Conclusions

- Exciting era for Higgs boson searches at the Tevatron
- CDF is thoroughly searching for SM and BSM Higgs bosons (Many other searches that were not covered here)
- Reaching sensitivity to SM Higgs over full mass range

- No evidence for signal found yet...
- Sensitivity $\sim$ 3.2 times SM at low mass
- Tevatron performing great, so luminosity quickly increasing! ($>$ 2 fb^{-1} / year)
- Tevatron will exclude over the full mass range with 8-10 fb^{-1}
- Stay tuned!



Exclusion has begun!

2 σ excess is likely with 10 fb^{-1} !

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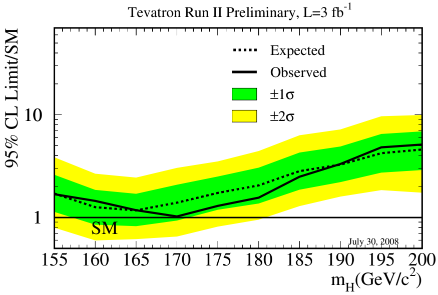

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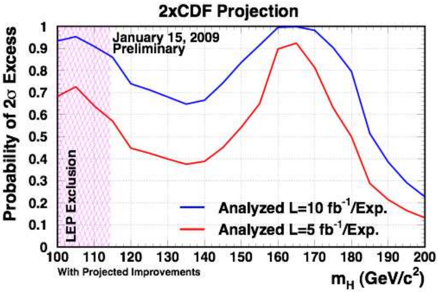

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Thank you!

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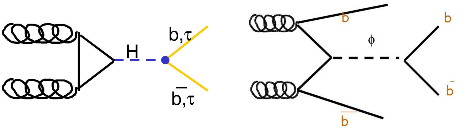
Backup

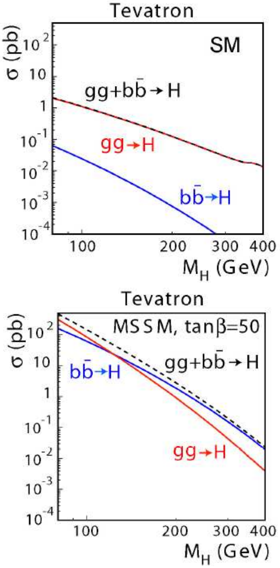
BACKUP

Beyond the Standard Model Higgs

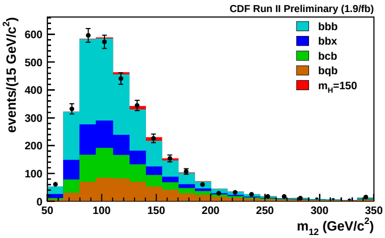
- Many Beyond the Standard Model Higgs possibilities

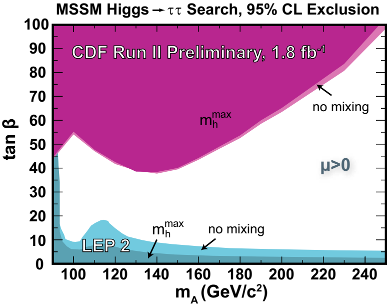


- MSSM Higgs with enhanced couplings to *b* quarks and tau leptons at large tan β
  - 5 Higgs bosons: h, H, A, H^{+}, H^{-}
  - A degenerates with other neutral Higgs at large tan β (ϕ = A, h, H)
  - Limits tan β vs m_A
- Fermiophobic Higgs with enhanced couplings to W bosons or photons



MSSM Higgs





- $b\phi \rightarrow bbb$
  - Require 3 b-jets, Search for peak in di-b-jet mass distribution of leading jets
  - Challenge: understanding quark content of the 3 jets
    - CDF: Vertex mass fi ts
- $\phi \rightarrow \tau^+\tau^-$
  - 1 leptonic tau + 1 leptonic or hadronic tau
  - Pure enough to search for direct production
  - Challenge: understanding tau ID efficiency
    - Large W and Z samples for calibrating and testing